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ABSTRACT. It is shown that energy production due to ionization losses of fast particles, originating on the sun, is sufficient to explain flare emission and that heating of the gas should take place during the relaxation time of energy balance in the flare. The dependence of ionization energy losses of fast particles on time is computed on the basis of existing conceptions on the spectra of fast particles. It is shown that this dependence is in agreement with the photometric curves in H_α obtained for flares. It has also been found that the emission increase in the H_α and L_α lines during flares should not be observed simultaneously.

I. Initial Data /86*

It is well known that many chromosphere flares are accompanied by an increase in cosmic ray intensity on the earth. Solar emission of particles with energies on the order of 10^8 - 10^{10} eV is frequently discussed (Ref. 1-10). Different researchers have agreed that for large flares the number of particles produced with great energy is on the order of 10^{33}. On the average, we may talk about particle energy on the order of 10^9 eV. This conclusion was reached, for example, by comparing (Ref. 7, 8, 9).

A. B. Severnyy (Ref. 11), Dorman (Ref. 7), and A. B. Severnyy and V. P. Shabanskiy (Ref. 12) in particular detail examined the problem of possible mechanisms by which particles are accelerated on the sun during large chromosphere flares. It was found from a theoretical investigation of the mechanism for particle acceleration on the sun that during flares on the sun, up to 10^4 particles are accelerated in 1 cm^3 of the chromosphere volume. Their energy may reach 10Bev. Based on purely energy considerations, S. I. Gopasyuk (Ref. 13) found that $3 \cdot 10^{34}$ particles must be accelerated in a flare, if it is assumed that on the average their energy equals 10^9 eV. Assuming that the volume of the flare is $3 \cdot 10^{27}$ cm^3 and that the number of the particles equals 10^{33}, we find that 1 cm^3 of the flare volume contains $3 \cdot 10^5$ particles.

We took data from (Ref. 4-16) on the results derived from a spectroscopic /87
study of chromosphere flares. According to these data, 10^7 hydrogen atoms on

*Note: Numbers in the margin indicate pagination in the original foreign text.

the second level and $2.3 \cdot 10^6$ hydrogen atoms on the third level are contained in 1 cm^3 of the flare. The total density in the flares is different according to data given in different studies. We decided on a value of $5 \cdot 10^{12}$ atoms per 1 cm^3 (10^{-11} g/cm^3). This value is somewhat higher than the customary value for the chromosphere at an altitude on the order of 2000 km above its base. For the calculations, we assumed that the chromosphere consists entirely of hydrogen. The brightness of the continuous spectrum close to the H_α line is on the order of $4 \cdot 10^5$ $erg/cm^2 \cdot sec$ per angstrom for the center of the solar disc. Only flares of the 2+ and 3 scale caused a considerable increase in cosmic ray intensity. According to (Ref. 17), it may be assumed that their area comprises 1000 million fractions of the solar disc. This is $3 \cdot 10^{19}$ cm^2. If it is assumed that the flare thickness equals 10^8cm, then its volume equals $3 \cdot 10^{27}$ cm^3. Cosmic rays reach the earth with delays whose magnitude may change from 20 - 30 minutes up to several hours. It may be assumed that part of this delay is caused by retardation of rapid particles on the sun due to the influence of the magnetic fields. The gyration radius of particles with energies of 10^9 eV will be less than a kilometer even in a small magnetic with a strength of 100 gauss, since $r = \frac{cp}{eH}$. It thus follows that, if the particle pulse direction does not coincide with the magnetic field, the particle will move along a spiral. The configuration of the magnetic fields in the flare region may be such that the particle is greatly delayed in leaving the vicinity of the sun. We may assume that the delay time of rapid particles in the chromosphere of the sun equals the duration of the flare, and is 10^3 sec. It may be shown that protons having great energies may be entirely responsible for those phenomena which are observed optically in the lines of hydrogen. This possibility was first examined by A. B. Severnyy (Ref. 16).

II. Energy Losses by Particles

This section presents the first preliminary calculations, for which it was assumed as the first approximation that each cubic centimeter of flare volume contains 10^5 particles with energies of 10^9 eV.

Moving in the chromosphere, the rapid particles interact with the atoms of surrounding gas, which decreases their energy. The energy losses are partially related to bremsstrahlung of rapid particles in the electric field of nuclei. The energy losses are partially a result of elastic collisions, and are partially related to losses in ionization and the excitation of surrounding atoms (ionization losses).

In this article, we shall not investigate losses due to bremsstrahlung, since this energy is liberated in the form of γ-quanta, which are barely absorbed in the atmosphere of the sun and pass to the outside without hinderance.

The studies (Ref. 18, 19) present the relative probabilities of a different type of collisions for electrons moving in hydrogen. It is known that at large velocities protons behave exactly like electrons moving at the same velocity (Ref. 19). This distribution of probabilities for a different type of collisions depends slightly on the particle energy. Roughly speaking, 10% of the ionization energy losses is expended on elastic collisions, 30% on ionization, and 60% on excitation of atoms. 40-45% is expended on excitation of the second level, 7% on excitation of the third level, and 3% on excitation of the fourth level. As a result of a rapid proton passage, due to ionization of atoms, secondary electrons appear which also have great energies. The probability that such electrons will appear is inversely proportional to the square of their energy (Ref. 20). In their turn, these electrons lead to excitation and ionization of atoms. The process of energy fractionation will occur until the particle energy is no less than the ionization energy, or does not compare with the thermal energy of gas particles (Ref. 21). The maximum energy of secondary electrons may be determined from the formula

$$Q_{\max} = \frac{2m_e c^2\beta^2 M^2}{\left(m_e^2 + M^2 + \frac{2m_e M}{\sqrt{1-\beta^2}}\right)(1-\beta^2)}, \qquad (1)$$

where M is the particle mass. Assuming that the energy of primary protons equals 10^9 eV, we find that $Q_{max} = 2.4 \cdot 10^6$ eV, which corresponds to an electron velocity of $2.5 \cdot 10^{10}$ cm/sec. Thus, we have found an explanation for the formation of relativistic electrons, which are responsible for the continuous emission of flares which is sometimes observed (synchrotron emission) (Ref. 22).

In order to determine the magnitude of ionization losses, we employ the formula given in (Ref. 23)

$$k = \frac{4Nz^2\left(\frac{Z}{A}\right)\pi r_e^2 m_e c^2}{\beta^2}\left[\ln\frac{2m_e c^2\beta^2}{(1-\beta^2)I(Z)} - \beta^2\right], \qquad (2)$$

where k is the energy loss per 1 g/cm^2, N -- the Avogadro number, the quantities z, Z, and A for rapid protons moving in hydrogen equal unity, r_e -- the classical electron radius, m_e -- its mass, I (Z) -- the mean "excitation and ionization potential" assumed to equal 13 eV. We performed calculations for protons with a velocity of u = 0.875 c, i.e., with an energy of about 10^9 eV. The losses equal $4.7 \cdot 10^6$ eV per 1 gram. For intensity of 10^{-11} g/cm^3, this comprises $k' = k\,\rho \approx 10^6$ eV per 1 second, or about $1.5 \cdot 10^{-6}$ erg/sec. Since we assume that 1 cm^3 contains 10^5 rapid protons, the total liberation of energy due to losses of rapid particles comprises $E = 10^5 \cdot 1.5 \cdot 10^{-6} = 0.15$ erg/cm^3·sec. In 1000 seconds, this gives $4.5 \cdot 10^{29}$ erg over the entire flare volume, which corresponds to the total energy emitted by the flares (Ref. 10). The liberation of energy in a column with a cross section of 1 cm^2 is $1.5 \cdot 10^7$ erg/cm^2·sec.

We may estimate the number of pairs of ions formed by a proton having this energy. It is proportional to the expenditure of energy on ionization losses, and the proportionality coefficient represents the average energy expenditures on one ionization act. This coefficient barely depends on the nature of the substance, and approximately equals 30 eV (Ref. 21, 24). Consequently, $dn_i = \frac{10^6 \cdot 10^5}{30} = 3.3 \cdot 10^9$ pairs per 1 cm^3/sec. Ionization equilibrium is established in the flares very rapidly (Ref. 25). The number of ions in a cubic centimeter may be determined from the steady-state equation

$$dn_i = n_i n_e C\ (T) \tag{3}$$

If we assume that $n_i = n_e$ and $C\ (T) = 4.0 \cdot 10^{-13}$ [Ref. 26], then $n_i \approx 3.6 \cdot 10^{11}$ cm^{-3}. This corresponds to the ionization $x = \frac{n_i}{n} \approx 0.07$. A comparison of this quantity with the expected value for the chromosphere at these altitudes (Ref. 27) shows /89 that only due to ionization by rapid particles can the electron density in a flare substantially exceed the electron density in the surrounding chromosphere.

III. Flare Emission

The monochromatic brightness of a flare at different wavelengths may be calculated according to the following formula (Ref. 13)

$$I_{ik} = I_{\lambda_0}\overline{\Delta\lambda} = \frac{N_k}{N_i} \cdot \frac{2hc^2}{\lambda_0^5} \frac{g_i}{g_k} \int_0^\infty (1 - e^{-\tau_\lambda})\, d\lambda, \tag{4}$$

where N_k and N_i are the numbers of atoms on the upper and lower levels, respectively, for the transition under consideration in 1 cm^3, τ_λ -- optical thickness of the flare in the given wavelength. For L_α, $\overline{\Delta\lambda} \approx 9.3 \cdot 10^{-8}$ cm according to calculations of Severnyy (Ref. 28). According to the data presented in (Ref. 14 and 29), $I_{H_\alpha} = 7\text{-}8 \cdot 10^6$ erg/cm^2·sec·ster. According to formula (4) it was found that $I_{L\alpha} = 2.1 \cdot 10^6$ erg/cm^2·sec·ster. Rocket measurements during flares revealed no significant intensification of solar radiation in L_α (Ref. 30-31), and $\sim 10^7$ erg was obtained from other very uncertain measurements. As we may see, radiation in the H_α and L_α lines is approximately the same. Neither can a great deal of energy be emitted in the Lyman continuum, since there are very many absorbing atoms for it, just as for L_α. According to data in (Ref. 33), it may be shown that even if recombination is the basic mechanism for flare emission, the intensity of the H_α line exceeds the intensity of the Balmer continuum by several factors. Observations did not reveal any significant Balmer continuum in the flares. Consequently, radiation in L_α and H_α, which are comparable to each other and which remove approximately $1.5 \cdot 10^7$ erg/cm^2·sec on the whole, plays the fundamental role in energy removal. As was shown in Section II, $1.5 \cdot 10^7$ erg/cm^2·sec is liberated due to ionization losses in a column having the cross section of 1 cm^2. This closely corresponds to that which much be removed from 1 cm^2 of the flare surface by radiation in L_α and H_α. Surface brightness of a flare in H_α is a little greater than the brightness of the continuous spectrum in the vicinity of the H_α line, calculated for 1 Å, which equals $4 \cdot 10^6$ erg/cm^2·sec.

Let us determine the amount of quanta and the total energy removed by radiation in H_α during recombinations following the flight of a rapid particle: resulting from excitation of the third level (assuming that they all produce H_α quantum in the last analysis), and resulting from excitation of higher levels (assuming that half of the excitations of the fourth level and a fourth of the total number of excitations of higher hydrogen levels leads to radiation of H_α quanta). Allowance for radiation in the remaining lines of the Balmer series changes the results obtained very little. We can only overestimate the energy removed in the H_α line if we assume that each ionization event leads ultimately to the radiation of one H_α quantum. Based on Section II, we know the total amount of ionization and excitation energy liberated due to ionization losses, as well as the total number of pairs of ions formed as a result of the flight of a rapid proton. It is found that as a result of these processes only $5 \cdot 10^9$ H_α quanta in all are formed, or less than $2 \cdot 10^{-2}$ erg/cm^2·sec. Consequently, the radiation of H_α, formed as a result of ionization and excitation directly during the flight of rapid particles, cannot remove all of the energy /90 liberated due to ionization losses, and the temperature of the region begins to increase. We thus arrive at the natural result that the temperature and ionization must rapidly increase at the beginning of a flare, since supplementary radiation in the L_α line does not leave the region under consideration in general (see below). This increase must continue until the number of hydrogen atoms on the third level reaches the observed value $n_3 = 3 \cdot 10^6$ cm^{-3}, when radiation in H_α can remove all of the energy liberated per unit volume. We may determine the corresponding temperature by two methods: in the first place, we may assume that the distribution between the first and third levels is given by the Boltzmann formula, i.e.,

$$\frac{n_3}{n_1} = 9 \cdot e^{-\frac{12.01}{kT_e}} = \frac{3 \cdot 10^6}{5 \cdot 10^{12}},$$

from which we have $T_e = 8500$°K. In the second place, we may assume that, due to deviations from thermodynamic equilibrium, overpopulation of the first level occurs. This means that the ratio n_3/n_1, given by the Boltzmann formula, is ten times smaller than the observed value of n_3/n_1 (Ref. 34). We then find that $T_e = 10^4$°K. From this point on, we shall assume that T_e equals $9 \cdot 10^3$°K in the flares. Ionization at this temperature may be determined according to (Ref. 35). It approximately equals 0.2. This value is greater than the value of ionization produced by the flight of rapid particles directly. This fact is very important since more than 20 erg per each cubic centimeter are necessary for increasing the ionization from a value corresponding to 5000°K (chromosphere) up to a value corresponding to 10,000°K. This energy is liberated only in

$\frac{20}{0.15} \approx$ 130 seconds. The energy is also used in increasing the kinetic energy of gas particles -- about 4 erg per 1 cm^3.

Thus, as a result of the interaction of rapid particles in the region of the flare, the temperature and ionization first increase, reaching values which are close to those actually observed in flares.

After reaching an equilibrium (in terms of the balance of energy) state, the H_α and L_α radiations produced in the state remove almost all of the energy liberated during the flight of rapid particles. The brightness of the flare in H_α will thus correspond to the observed brightness. Flare emission in other lines remove a comparatively small portion of the energy. Brightness changes (and energy removal) are initiated, as we have already observed, not immediately after the occurrence of supplementary radiation, but over a period of time which is close to the average time a quantum remains in the region under consideration. According to (Ref. 36), this may be estimated as $\bar{t} = \bar{z}\,(t_1 + t_2)$, where $\bar{z}$ is the average number of scatterings, and $t_1 + t_2$ is the time between two consecutive moments of quantum radiation. Under the conditions which we are investigating, the time passed by a quantum in the path between two scatterings (t_2) is very small as compared with the time when the quantum occurs in the absorbed state $t_1 = \frac{1}{A_{ik}}$. $\bar{z} = \frac{\tau_0^2}{4}$, where $\tau_0 \approx L\, n_{ik} k$, τ_0 is the optical thickness, $k \approx 10^{-13}$, $L = 10^8$ cm. Consequently, for H_α, $\tau_0 = 10^{-5} \cdot 10^7 = 10^2$, and for L_α, $\tau_0 = 10^{-5} \cdot 5 \cdot 10^{12} = 5 \cdot 10^7$, $A_{12} = 4.7 \cdot 10^8$, $A_{23} = 4.4 \cdot 10^7$. Thus, for H_α we have

$$\bar{t} = \frac{10^4}{4 \cdot 4{,}4 \cdot 10^7} = 6{,}7 \cdot 10^{-5} \text{ sec.}$$

and for L_α, we have /91

$$\bar{t} = \frac{25 \cdot 10^{14}}{4 \cdot 4{,}7 \cdot 10^8} = 1{,}3 \cdot 10^6 \text{ sec.}$$

According to Osterbrock (Ref. 37), we must employ formula $\bar{z} = 6 \cdot 10^{-6}\, \tau_0^2$, from which we obtain $\bar{t} = 10^2$ seconds. However, Osterbrock does not take into account the processes of real absorption, and due to this fact the time from the moment when supplementary radiation occurs up to the moment when it is observed by us is greatly increased. Therefore, an increase in radiation in the L_α line must not be expected when a flare occurs in H_α, but later. As calculations show, this delay may amount to several tens of minutes. A similar result was obtained in (Ref. 38). This must be kept in mind when attempts are made to measure the flare emission in H_α by means of rockets and satellites. In addition, this delay naturally leads to washing out in time. Thus, an increase in radiation in H_α may be small and longer than in H_α, especially if a gas layer with great optical thickness is located above the flare.

IV. Dependence of Energy Liberation on Time

The method presented in Section I for calculating the energy liberated in a medium did not take into account the features of particle energy distribution or changes in energy liberation with time in the region under consideration. If such a calculation is attempted, with allowance for the energy spectrum of the particles, the fact must be kept in mind that there are many more particles with low energy than there are with high energy. Thus, it was pointed out in (Ref. 39) that Van Allen obtained 10^{36} particles with energies greater than 30 Mev when observing a stream of particles from a strong flare. We have confined ourselves to particle energies above $5 \cdot 10^7$ Mev, and we shall assume that the total energy of all the particles equals the total energy which we assumed in the initial preliminary calculation. Consequently, it equals $10^{33} \cdot 10^9 \cdot 1.6 \cdot 10^{-12} = 1.6 \cdot 10^{30}$ erg. It is assumed that $N(E) = \frac{A_\gamma}{E^\gamma}$ for the differential energy spectrum of particles where $\gamma = 3$ (Ref. 40, 41). Since the spectrum of particles may change toward an increase in γ when particles move toward the earth, we have also investigated the case $\gamma = 2$. It was assumed in the calculations that a single, brief injection of particles into the flare region occurs. From this point on, we shall proceed on this assumption. Let us calculate how much energy is given off by all the particles as a result of ionization losses. A particle with the energy E loses $k(E)\rho\beta c$ energy in one second, and all the particles lose the following in the first moments

$$\frac{dQ}{dt} = \int\limits_{5 \cdot 10^7}^{\infty} N(E) \frac{dE}{dt} dE.$$

The particle spectrum changes in time. Therefore, we must assume that N is a function of E and t. We find from the condition assumed above that for $\gamma = 3$, the total number of particles must equal $5 \cdot 10^{34}$, and $A_\gamma = A_3$ equals $1.6 \cdot 10^{26}$ (the energy is expressed in ergs). For $\gamma = 2$, 10^{34} particles are correspondingly obtained and $A_2 = 8 \cdot 10^{29}$. Energy is primarily liberated in a medium due to ionization losses of protons with energies less than 10^9 eV. We may employ the non- /92
relativistic approximation, which greatly simplifies the calculations, for such particles with a fairly small error. The energy losses $\frac{dE}{dt} = k\rho u$. According to formula (2), the quantity k contains the factor $[\ln \frac{2m_e c^2 \beta^2}{(1-\beta^2)\, I(Z)} - \beta^2]$,

which changes from 6.7 to 14.8 when the particle energy changes from 10^7 to 10^{19}eV. We shall disregard such a small change, and shall assume that this factor equals 10. Then $k = 0.31 \cdot 10^7 \beta^{-2}$ eV per 1 g. We thus have $\frac{dE}{dt} = \frac{5.3 \cdot 10^4}{u} = \frac{4.7 \cdot 10^{-8}}{\sqrt{E}}$ erg/sec. At a certain moment t the number of particles with the energy E will be N_1 (E, t). This is exactly the number of particles which at the moment t = 0 have the energy x, i.e., $N_1 (E,t)\, dE = N_1 (x,t_0)\, dx = N(x)\, dx$, where x is the quantity which is related with E by the relationship

$$E(t) = x - \int K dt, \quad \text{where } K = \frac{B}{\sqrt{E}}.$$

After integration, we obtain

$$x = (Ct + E^{3/2})^{2/3}. \tag{5}$$

The initial condition is apparently for t = 0, x = E, $B = 2/3C = 4.7 \cdot 10^{-8}$. We finally have

$$\int N[E(t)]\, K(E)\, dE = \int N(x)\, K(E)\, dx = \int \frac{A_\gamma}{x^\gamma} E(x)\, dx \tag{6}$$

and

$$\frac{dQ}{dt} = A_\gamma B \int\limits_{x_0}^{\infty} \frac{dx}{x^\gamma (x^{3/2} - Ct)^{1/3}}, \tag{7}$$

where γ = 2 and 3, $x_0 = 5 \cdot 10^7$ eV $= 8 \cdot 10^{-5}$ erg. The integration limits must be selected from x_0 to ∞, while E > 0. In the time t_1, which is determined from relationship $Ct_1 = x_1^{3/2}$ for particles with initial energy values which are less than x_1, E (t_1) becomes equal to zero. Therefore, the integral must be selected, not from x_0, but from x_1 to ∞ in the expression for the energy liberation dQ/dt. In practice, the integral may be selected from $(Ct)^{2/3}$ to ∞. In our case, the boundary $(Ct)^{2/3} = x_0$ lies around t = 10. For the cases t = 10, the integral (7) may be represented as follows

$$\frac{dQ}{dt} = A_\gamma B \int\limits_{x_0}^{\infty} \frac{dx}{x^{\gamma + 1/3}}. \tag{8}$$

For t > 10, the integral acquires the following form

$$\frac{dQ}{dt} = A_\gamma B \int\limits_{(Ct)^{2/3}}^{\infty} \frac{dx}{x^\gamma (x^{3/2} - Ct)^{1/3}}. \tag{9}$$

Let us set $x = (Ct)^{2/3}\, y$. We then have

$$\frac{dQ}{dt} = \frac{A_\gamma B}{(Ct)^{\frac{2\gamma-1}{3}}} \int_1^\infty \frac{dy}{y^\gamma (y^{2/3}-1)^{1/2}}. \tag{10}$$

The integral converges. There may be some doubts only about the lower limits, but setting $y = 1 + \eta$ and $\eta \to 0$, we may readily see it is correct. The integral

$$F_\gamma = \int_1^\infty \frac{dy}{y^\gamma (y^{2/3}-1)^{1/2}} \tag{11}$$

for the case $\gamma = 2$ may be readily selected according to the formula for binomial differentials (Ref. 42) and equals 1. For the case $\gamma = 3$, by numerical integration we find that $F_3 = 0.66$.

Thus, for $\gamma = 2$

$$\frac{dQ}{dt} = 5{,}34 \cdot 10^{29} t^{-1}, \text{ and } D = \frac{dQ}{dt} \Big/ V = 178 t^{-1} \text{ erg/cm}^3 \cdot \text{sec}.$$

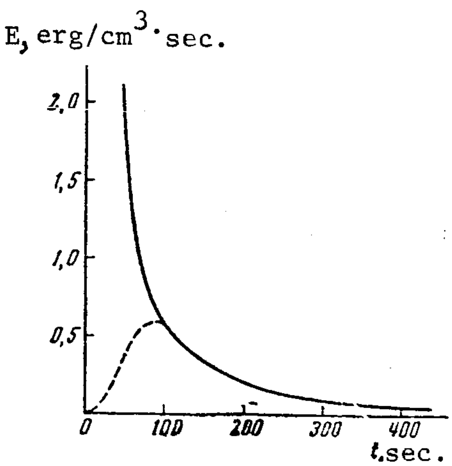

Figure 1. Dependence of Energy Liberation in a Medium Upon Time for the Case $\gamma = 3$.
The Dashed Line Designates the Assumed Behavior of the Flare Brightness in H_α Up to the Maximum.

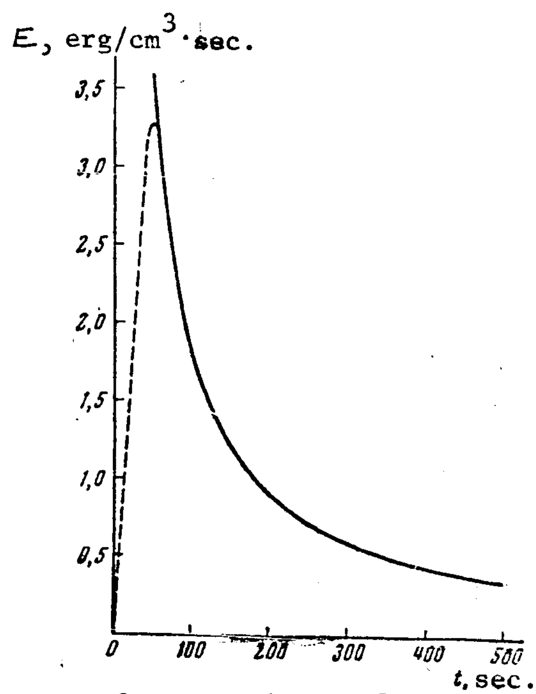

Figure 2. Dependence of Energy Liberation in a Medium Upon Time for the Case $\gamma = 2$.
The Dashed Line Designates the Assumed Behavior of the Flare Brightness in H_α Up to the Maximum.

For $\gamma = 3$, we have

$$\frac{dQ}{dt} = 4{,}14 \cdot 10^{30} t^{-4/3}, \text{ and } D = \frac{dQ}{dt} \Big/ V = 1380 t^{-4/3} \text{ erg/cm}^3 \cdot \text{sec}.$$

For t = 0, we obtain for $\gamma = 2$, D = 12 erg/cm^3·sec and for $\gamma = 3$, D = 18 erg/cm^3 sec. For t = 10, we may calculate $\frac{1}{x_0^{1/2}} \int\limits_{2x_0}^{\infty} \frac{dx}{x^{\gamma}}$, , which yields 9 erg/cm^3·sec for $\gamma = 2$ and 5.6 erg/cm^3·sec for $\gamma = 3$. The computational results are given /94 in Table I, where the values of $D = \frac{dQ}{dt} \Big/ V$ are given in erg/cm^3·sec.

TABLE I

γ	t, sec.							
	0	10	50	100	200	300	400	500
3	18	5,6	2,1	0,59	0,21	0,1	0,06	0,04
2	12	9	3,6	1,8	0,9	0,6	0,45	0,36

Figures 1 and 2 show the dependence of energy liberation on time. It also schematically shows how to represent the development of flare emission in H_{α}.

As has been indicated above, about 24 erg per 1 cm^3 is necessary for heating and ionizing the gas in a flare. Graphic integration of the distributions obtained shows, however, that the area between the curve for energy liberation and the emission curve in H_{α} in the period before the flare maximum corresponds to a value which is much greater. The curves for the dependence of radiation intensity on time, which have been shown in detail in Figures 1 and 2, are frequently encountered in the photometry of flares [see, for example, (Ref. 43)]. A small change in the particle spectrum, and their repeated and prolonged injection can explain all the variety of flare emission behavior in H_{α} with time.

V. Concluding Remarks

We found in Section II that particles with energies of 10^9 eV lose 10^6 eV per one second, and lose their entire energy in 1000 seconds. Whether a particle leaves the atmosphere of the sun or not greatly depends on the configuration of the magnetic fields. There is no doubt that particles with larger energies have greater chances to leave the atmosphere of the sun and to be observed on the earth. It may also be assumed that the acceleration process occurs less vigorously for weaker flares, and the particles for these flares have smaller energies. These particles very rapidly lose all of their energy. For example, it may readily be calculated according to formula (2) that particles with an energy less than 10^8 eV lose all of their energy most rapidly in the chromosphere during a flare. As a rule, an increase in their number will not be observed on the earth along with weak chromosphere flares. However, emission of such weak flares, may also be due to the ionization losses of rapid particles.

Based on formulas given in (Ref. 44), we calculated that the Maxwell velocity distribution is established for the majority of particles more rapidly than these particles can recombine. However, it may be expected that many ions with great velocities will recombine, which leads to the formation of wide wings on the H_α line. An unusually large population of the third hydrogen level, as compared with the fifth level, was noted in (Ref. 14, 15). This deviation may probably be explained by the overpopulation of the lower hydrogen levels, which is related with deviations from the state of local thermodynamic equilibrium (Ref. 34).

It may be seen from the statements given above that the occurrence of excess emission in H_α may be explained, by assuming that these processes are related with the passage of rapid protons in the chromosphere.

Apparently, a basic factor in a flare is the slow accumulation and then rapid transition of the magnetic field energy into another form, and the acceleration of particles which thus occurs. In their turn, these particles, moving in the chromosphere, produce the observed emission.* /95

A. B. Severnyy (Ref. 45) investigated the paths for the initial increase in intensity in the region of the flare. The increase in temperature and ionization on the first developmental stage of the flare occurs as we discussed above. At the same time, a brightness increase in H_α occurs for several minutes. An increased brightness in H_α is observed continuously, as long as there are rapid particles in the region of the flare observed in H_α. After this, the emission becomes the same as in the surrounding chromosphere as the density of the radiation field in L_α decreases.**

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* The conclusion that the emission observed in the flare is not the main process, and may be readily explained by the small increase in density and temperature of the gas, follows from several studies on flare spectroscopy performed in the observatory. This conclusion was reached after an examination of flare properties by co-workers at the observatory, V. L. Khokhlovoy, N. V. Steshenko, the author, and others.

** The author is indebted to N. V. Steshenko for these remarks.

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